DESIGN ENGINEERING WITH FOAMS AND PLASTICS TO ENHANCE VEHICLE SAFETY

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ABSTRACT

Foams and Thermoplastics are materials that have an increasing use to obtain safer and lighter cars. Utilizing the integration potential of plastics, considerable cost efficiencies are obtained. A key element is that predictive modelling is used to achieve optimum system solutions. In this paper both foams and plastic solutions are presented in different applications in the car providing energy absorbing capabilities and therefore enhancing the safety performance. The first area is that of structural foams in the car body cavities to enhance crash performance. The second area concerns integrated thermoplastic structures in the interior for absorbing impact energy while providing aesthetics and other functionality. The third is that of innovative thermoplastic extruded foam with superior energy efficiency characteristics, applied in head impact environment in the interior of the car as well as potentially in pedestrian safety solutions.

Structural Foam Treatment to Improve Total Body Performance

Filling rigid foam inside the cavities of a vehicle body is being used for NVH (noise, vibration & harshness) as well as for stiffening purpose and crash energy management.
Typically the foam is injected into hollow sections such as longitudinal rails, pillars or the rocker area sealing the cavity and increasing the stiffness of the components (Figure 1)

Figure 1 Foam Application in B-Pillar to Roof Rail Area.

Medium density foams in a range of 120 to 190 kg/m^3 are used to improve the global stiffness and handling feel of the body structure including a strategic barrier sealing for better acoustics. For energy management purpose higher density foams are used; typically in a range up to 480 kg/m^3. With this treatment the collapse of a section under impact loading can be significantly reduced by controlling the displacements and maintaining the cross-sectional integrity.

Figure 2 Bending Test of hollow Tube.

Figure 3 Bending Test of Foam filled Tube.

Two-component polyurethane systems are a mix of polymeric MDI or isocyanate prepolymer and polyol blend or water/amine catalyst that react to form rigid, closed cell foam.

While conventional polyurethane foams dispense as a free flowing liquid based on polymeric MDI there is a high density foam available that behaves as a low flow, sag resistant, paste-type material.
This *BETAFOAM® 88100/88124* (ρ = 384 kg/m^3) includes low MDI emissions indicating that ventilation requirements may be greatly minimized compared to traditional requirements.
The compressive modulus of this foam is 125 N/mm^2 while the compressive strength is about 2 N/mm^2. Applied to the body structure significant performance improvements can be achieved.

Structural Foam helped the *Cadillac Seville* luxury car enabling IIHS offset barrier test performance improvement to highest rating possible without structural ‘tear-ups’ or styling changes required in the upper structure. To achieve this 0.65 kg of foam was added to the hydro-formed A-pillar upper.

The possibility of applying bulk-type sealants in any cavity shape – even in hydro-formed tubes – is one of the major advantages compared to engineered sealants. While the latter have to be designed as a separate part containing steel or plastic carriers, the foam technology can very easily be applied both for cost and mass efficiency. In addition, all physical prototype phases can be instantly optimised, allowing more than just a confirmation of the design.

To support both body engineering development and manufacturing integration, CAE Capabilities are needed for predictive engineering as well as tool try out to establish a foam shot matrix.

Structural Foam can be pumped from bulk containers into meter mix equipment. The proper mix ratio is in turn dispensed manually or robotically through a static/dynamic mixer equipped gun. The foam treatment is applied after the paint shop before the general assembly process takes place.
With the low MDI formulation and the manufacturing technology now available the application of foam treatment can be a step forward from a band-aid to an engineering solution within body development. Especially the support of the cross sectional integrity at impact loads gives a high potential in further optimizing body structures with regard to cross section dimensions, sheet metal gauges and material grades and costs.
To utilize the foam treatment as part of body engineering, both material characterization as well as modelling techniques for the area of predictive engineering need to be available. The non-linear material behaviour can be described properly by using low-density foam material models assuming that the Poisson ratio is zero. For the ***LS/DYNA*** FE-code a complete material model is available that was developed and confirmed on compressive and bending characteristics of pure foam specimens and foam/sheet metal components.

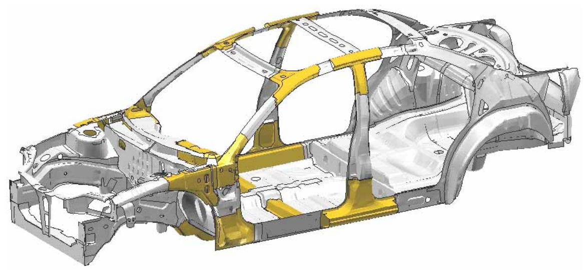

Figure 4 Joint Cavities of Body Structure for Foam Treatment.

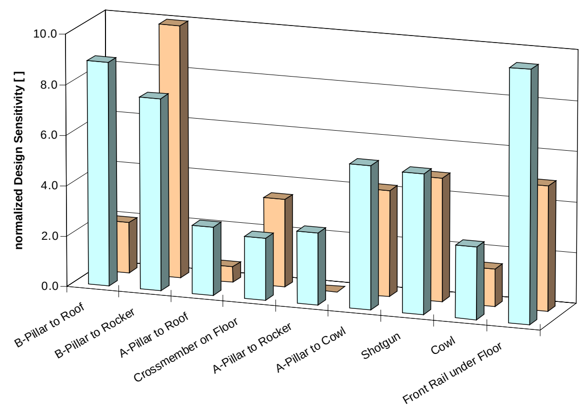

Figure 5 Potential of Different Locations for Foam Treatment.

With the use of design sensitivity analysis on body level the potential of the different locations for the foam treatment can be evaluated. This ensures the best ratio between applied bulk mass and performance improvement for both quasistatic and dynamic stiffness. The mass efficiency for the 1st torsional eigenmode of a vehicle body can be 1.5 kg/Hz or even better when using rigid foam treatment as a design approach.
Hence the treatment of structural foam is an interesting complement to the traditional sheet metal structure enhancing the body performance without any additional requirements on the package. The early involvement of the foam technology within the vehicle development process ensures the maximum benefit with regard to cost and weight reduction of the total system.
Also, new low MDI relieves environmental concerns further, improving the processability in the assembly plant.

Thermoplastic Parts and Systems to Meet Occupant Protection Requirements.

In the event of an accident, vehicle occupants are liable to collide with some parts of the interior trim. To prevent injuries through high forces and decelerations or sharp edges, components and systems need to be able to absorb energy in a controlled and ductile manner. Legislation, consumer organizations testing and OEM specific requirements are in place to ensure a minimum level of safety for the occupants. Plastic parts and systems are designed not only to provide aesthetics and functionality but also to integrate the impact requirements. Typically this leads to eliminating metal parts and reducing overall system weight and cost. However, in order develop plastic parts and systems with an integrated impact performance, high level CAE driven engineering needs to be performed to use plastics to their full potential. Over the years Dow Automotive has developed methodologies as well as the infrastructure in terms of material modelling, application testing and CAE expertise, which have enabled Original Equipment Manufacturers (OEM) to realize innovative integrated plastic systems.

One of the major challenges is that most thermoplastics have a material behaviour, which is dependent on temperature, deformation rate, aging and processing. To successfully develop robust integrated, energy absorbing plastic systems, a thorough understanding of material characterisation and modelling as well as material processing is needed.

<u>**Example 1: Plastic Knee Bolsters.**</u> In the United States, the federal motor vehicle safety standard FMVSS 208 covers the minimum safety requirement an instrument panel has to meet in order to protect unrestrained occupants when impacting the IP during frontal collisions. In Europe, new offset frontal crash legislation and new car assessment programs (NCAP) now also influence the design of the lower part of the instrument panel.

Over the last years plastic knee bolsters have been introduced for a range of different car platforms, complying with the FMVSS208. Knee bolster systems are designed and engineered to decelerate and manage the occupant lower torso energy while the occupant upper torso energy is decelerated by airbags. Plastic bolsters have provided a more cost-effective alternative to the traditional metal designs. Cost reductions originate from the combination of part count reduction, tool cost reduction and assembly cost reduction while meeting the functional performance. In addition to cost reduction also weight reduction has been achieved. In developing these plastic knee bolsters one has to rely more on CAE methods to design and optimize the bolsters prior to producing tools. Changing the plastic bolster by modifying the tool is more time consuming and costly than changing steel gauges, as has been the case for the traditional design, in order to optimize the bolster stiffness, so this predictive modelling capability is a key element.

With the aid of simulation techniques, a full plastic knee bolster of PC/ABS was developed, which does not require any additional metal parts.

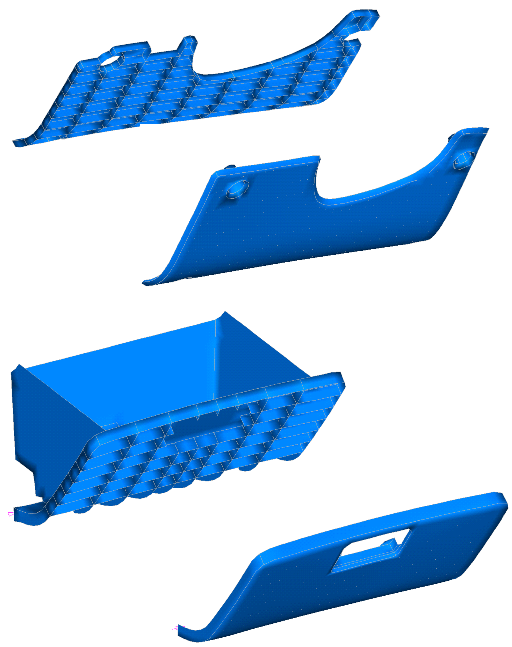

Figure 6 Driver and Passenger Side Plastic Knee Bolster for the Ford Cougar .

The first step in the development was to construct a plastic structure of the driver close out and of the glove box door on the passenger side. For both, these consist of two injection-moulded shells, one of them ribbed, which are then welded together. The stiffness of this structure is optimized for the quick load up while avoiding too high femur load peaks.

The next step was to improve and develop the baseline lower instrument panel structure to be able to absorb the knee impact energy. In the case of the Ford Cougar a total of 10 metal components where eliminated by integrating the energy absorption function in plastic parts and further optimization of some of the remaining metal components in the lower instrument panel. Furthermore a weight saving of 1.8 kg was achieved together with considerable cost savings.

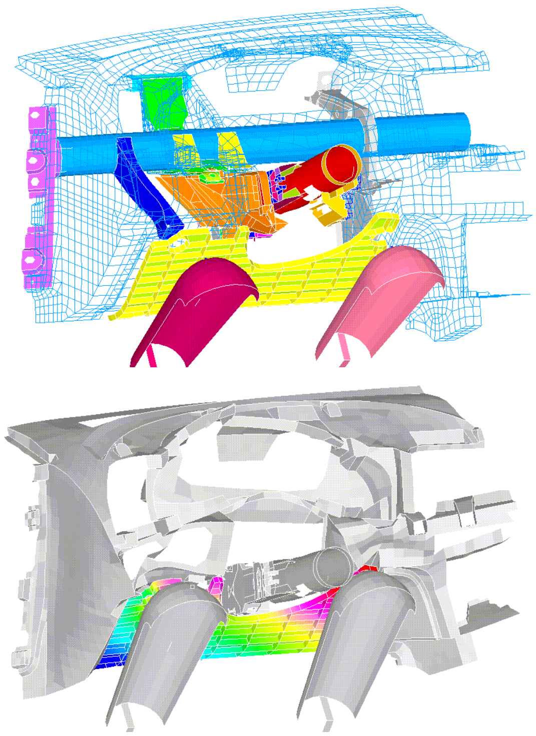

Figure 7 Driver Side Knee Impact.

Example 2: Fully Integrated Structural Instrument Panels. In the development of highly integrated plastic concepts it is important to use component and system testing to develop correlation studies and further enhance both design as well as overall methodologies. The correlation below (Fig. 8) shows the correlation of femur loads during a full vehicle crash with the corresponding simulation results.

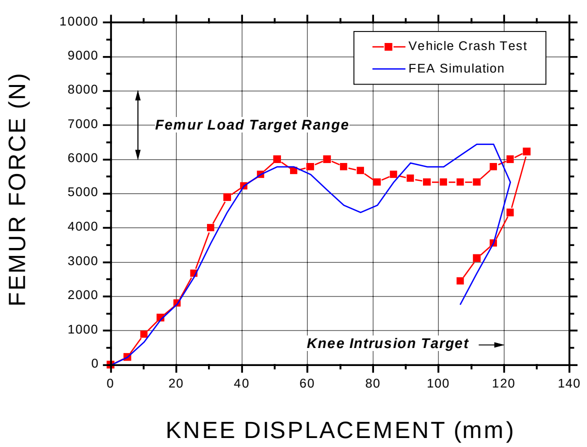

Figure 8 Correlation Between Full Vehicle Crash and Simulation.

This example concerns a development of the 1997 Dodge Dakota Fully Integrated Structural Instrument Panel where the metal cross car structure has been eliminated and replaced by an integrated plastic structure. In this design almost all of the energy under occupant impact is absorbed by the plastic structure.

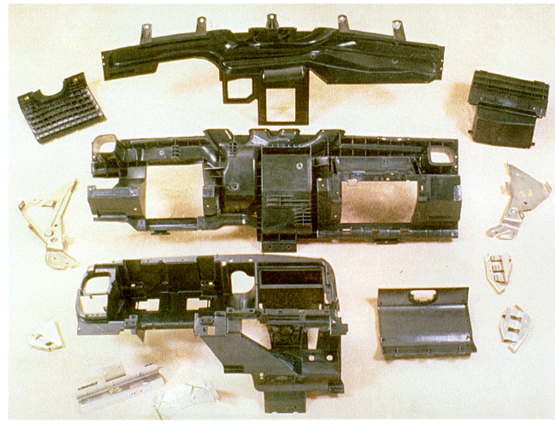

Figure 9 Dodge Dakota Structural Instrument Panel Parts.

It is evident that the highly loaded and deformed injection molded plastic components need also to be carefully optimized with respect to the processing.

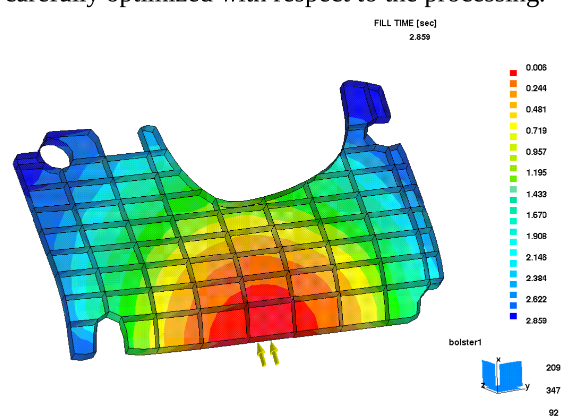

Figure 10 Optimization of Processing of Plastic Knee Bolster.

Filling simulations are used to develop the optimum gating and processing conditions to avoid weak spots in critical areas and to optimise processing.

High Efficient Energy Foam for Head Impact and Pedestrian Safety Compliance.

Head Impact Compliance. Federal legislation for head impact protection in upper automotive interiors (FMVSS 201U) has presented a unique energy management problem for the automotive industry (the dummy head injury criteria HIC(d) has to be below 1,000 for compliance). Due to extremely tight packaging conditions, energy absorbers are required to have efficiencies exceeding those of traditional foam materials. A unique oriented PP foam has been developed.

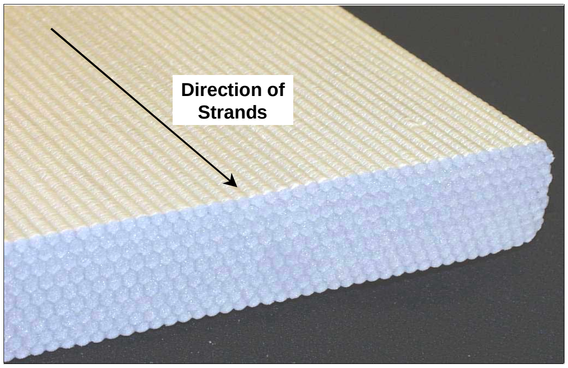

Figure 11 Oriented PP Foam board

The combination of EA mechanisms of this foam (compression, buckling and fracture) allows it to outperform other commonly used head impact countermeasures, within a given packaging space(Fig. 12, 14)

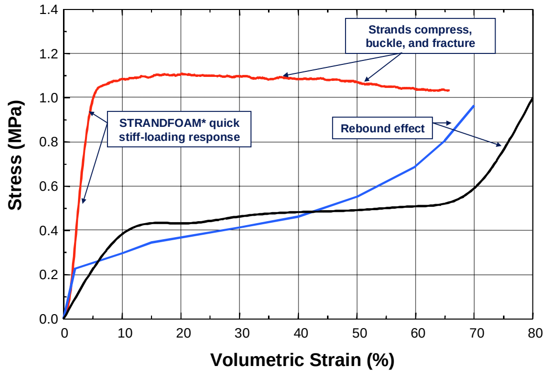

Figure 12 Compressive behavior of different EA foams. (94% EA efficiency for STRANDFOAM, EPP bead foam and PU foam show 50% EA efficiency), all samples tested in compression with 64g/l and 20mm thickness)

In order to successfully implement this foam into head impact applications, specific capabilities to support OEMs both late in the development stage as well as in early stage of development have to be available. Critical capabilities design guides, DOE, dynamic material characterization (Fig. 15), rapid prototyping (saw cutting, abrasive wire cutting, thermoforming) up to FEA expertise (Fig. 16). This culminates in the capability to predict, with high accuracy, the performance of the system under head impact loading and obtain good correlation with actual tests (Fig. 17).

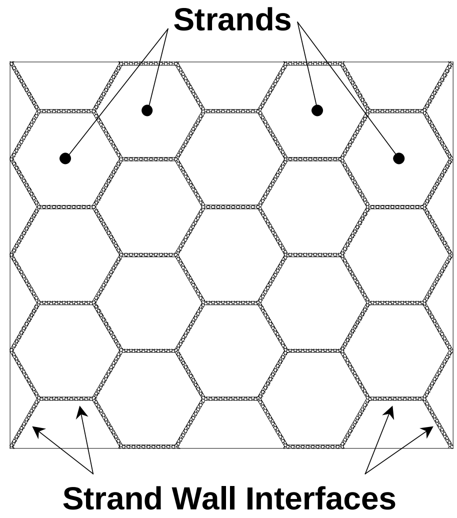

Figure 13 Illustration of strand interface.

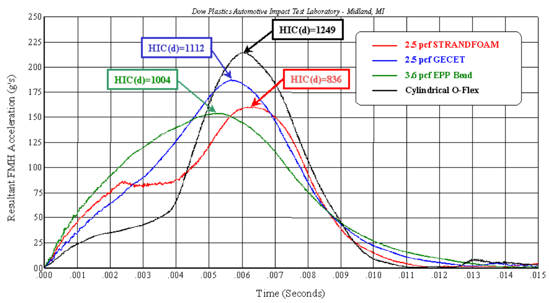

Figure 14 Component level FMH test for different head impact countermeasures.

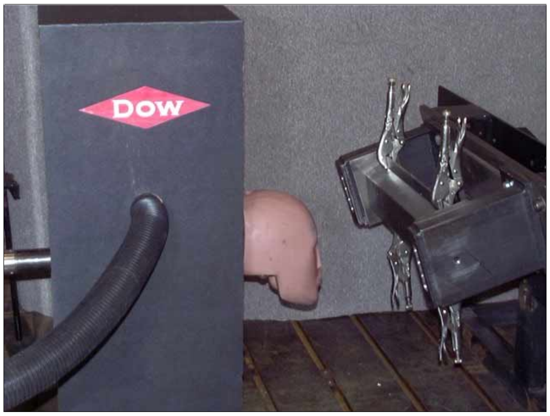

Figure 15 Experimental Test for FMVSS201U foam characterization.

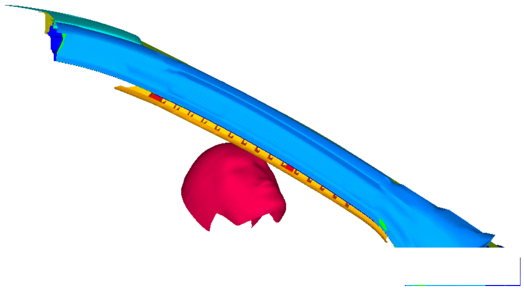

Figure 16 FEA on A pillar trim, according to FMVSS201U.

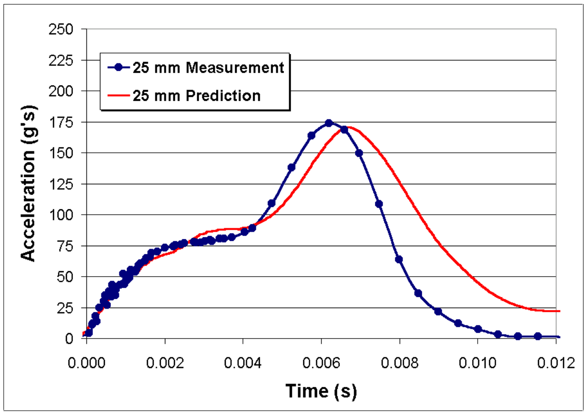

Figure 17 Correlation between Measured and Predicted Acceleration-Time Response of the Foam/BIW System.

<u>Design for Pedestrian Safety using Oriented PP Foam.</u> In the coming years, new regulations relating to pedestrian safety will be introduced in Europe. The intention of the proposed legislation is to ensure that front-end systems are designed to improve a pedestrian's chances of survival in collision with a car. These requirements will add a new dimension to the complexity of designing a vehicle front-end system. With the advent of pedestrian safety legislation a new set of constraints is introduced which often conflicts with the current requirements. The effective shape of the front end should be such that the loads are properly distributed and the knee joint deflections and rotations are below stipulated values.

Car manufacturers and their suppliers now face the challenge of designing for these new regulations. Various approaches are possible varying from extensive testing on the basis of current models to computer aided methods. The Dow Automotive approach presented here shows the advantages of initially conducting sensitivity analyses using CAE, comparing this with testing on current vehicles and then proposing solutions for future models. This approach leads to better understanding of the issues, reduces the cost of development and decreases the time to identify a design that can then be developed and tested.

The "Virtual Stiffness Profile" as shown in figure 18 depicts a representation of a possible stiffness distribution required to fulfil the pedestrian safety requirements.

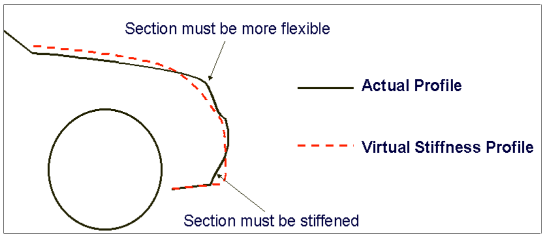

Figure 18 The "Virtual Stiffness Profile".

The design of the front-end and the general styling of the car has an enormous influence on the performance of the car in pedestrian impact situations. For instance, for the leg-form impact, where there are requirements on the tibia acceleration, the knee shear and the bending angle, the kinematics of the leg-form impactor are very important. For low bumpers, much of the energy of the impactor is transformed into rotation of the leg-form rather than being absorbed by the bumper. As the bumper is raised, the level of intrusion increases and the bumper absorbs more of the energy.

For a given design and styling the fine-tuning of the system to meet the combination of pedestrian safety, ECE42 and insurance requirements becomes a matter of defining the stiffness of the structure and the distribution of stiffness over the front-end. An innovative approach is adapted to define a "virtual stiffness profile" for the car, which can be used to optimise the structure (see figure 18). The current "traditional" bumper system normally uses a combination of an injection-moulded fascia with foam and possibly a second moulded part welded to the fascia. Such a system is already suitable for pedestrian safety, if the stiffness can be tuned to give the required response.

It is important when using foam systems that the efficiency is as high as possible. The foam system, PP oriented foams, described above, displays a highly efficient load-intrusion response, when compared to other foam systems (see figure 1). The foam is based on strands of PP foam which are fused together to form a honeycomb system. The force levels can be tuned based on density and spacing of the honeycombs. Using this foam, it is possible to maintain a broader range of options for the designer in terms of styling, minimising the packaging space required and tuning the response to fit the impact requirements. It was found with various studies that the packaging space can be reduced by 20-30% in many cases.

For loading close to fixations and the edge of the bumper, the solution has satisfy the pedestrian safety requirements and prevent damage to the chassis in the insurance impact. In this case the design of the fixations become very important. Developments are underway to examine the fixation points and possible combination of ribbed systems with foam.

Solutions for the bonnet of the car to control the loading on the head during pedestrian impact are also being considered. In most cases a sandwich approach is being taken, using a combination of metal, plastics and foam.

Once the effects and trends are understood, the task of designing for a specific platform becomes easier. The CAE approach is considered the most appropriate course in order to reduce testing costs and development time. For these developments, a range of capabilities to model the pedestrian impact testing and the front-end of the car need to be available. One such model is shown in figure 19. CAE is proving key to finding solution before testing begins.

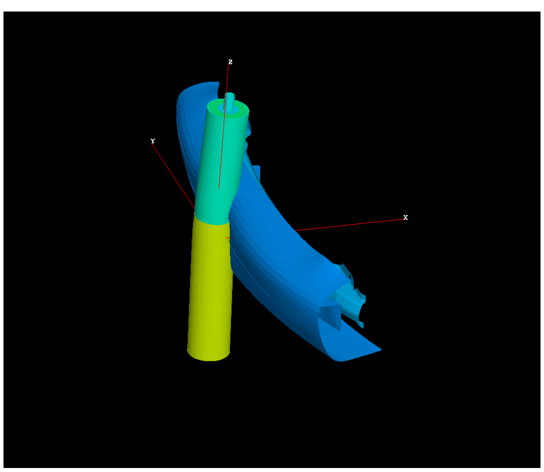

Figure 19 Example of leg-form impact modelling on a bumper system.

REFERENCES

1. Michael Paine , Vehicle Design & Research Pty Limited, “Personal observations on a pedestrian safety seminar” Adelaide, Australia on 25 & 26 February 1999.
2. EEVC Working Group 17 Report, “Improved test methods to evaluate pedestrian protection afforded by passenger cars”, December 1998.
3. Hardy, B.J, “Analysis of pedestrian accidents, using police fatal accident files and ships data”, TRL, April 1998, EEVC WG17 document 55.
4. Dipl.-Ing. Flavio Friesen, Dipl.-Ing. Marc Philipps, "Pedestrian safety analysis and optimisation of vehicle front ends in the scope of the EEVC-WG 10 test procedure", Institut für Kraftfahrwesen Aachen, RWTH Aachen VDI-Tagung "Innovativer Kfz-Insassen- und Partnerschutz", 30.09-01.10.1999, Berlin.
5. EuroNCAP Crash test reports, www.fia.com.
6. MADYMO User's Manual 3D v5.4, TNO Automotive, May 1999.
7. Gandhe, Gajanan V., Tusim, Martin H., “High Efficiency Energy Absorption Olefinic Foam”, SAE Technical Paer Series 199-01-0296, International Congress and Exposition, Detroit, March 1-4, 1999.
8. Naughton P., Cate P., “An approach to front-end system design for pedestrian safety”, SAE Technical Paper 2001-01-0353, International Congress and Exposition, Detroit, March 5-8, 2001.